RUNNING HEAD: Wellness, workload and injury risk

Subjective wellness, acute:chronic workloads and injury risk in college football

ABSTRACT

Acute:chronic workload ratios (ACWR) are associated with injury risk across team sports. In this study, one season of workload and wellness data from forty-two collegiate football players were retrospectively analysed. Daily 7:21 day exponentially weight moving average (EWMA) ACWR were calculated, and z-score fluctuations ("normal" "better" and "worse") in sleep, soreness, energy and overall wellness were assessed relative to the previous days ACWR and considered as an interactive effect on the risk of non-contact injury within 0-3 days.

55 non-contact injuries were observed and injury risks were *very likely* higher when ACWR's were 2SD's above (RR: 3.05, 90% CI: 1.14 to 8.16) and below (RR: 2.49, 90% CI: 1.11 to 5.58) the mean. A high ACWR was *trivially* associated ($p<0.05$) with "*worse*" wellness (r = -0.06, CI: -0.10 to -0.02), muscle soreness (r = -0.07, CI: -0.11 to -0.03), and energy (r = -0.05, CI: -0.09 to -0.01). Feelings of "*better*" overall wellness and muscle soreness with collectively high EWMA ACWRs displayed *likely* higher injury risks compared to "*normal*" (RR: 1.52, 90% CI: 0.91 to 2.54; RR: 1.64, 90% CI: 1.10 to 2.47) and *likely* or *very likely* (RR: 2.36, 90% CI: 0.83 to 674; RR: 2.78, 90% CI: 1.21 to 6.38) compared to "*worse*" wellness and soreness respectively.

High EWMA ACWR increased injury risk and negatively impacted wellness. However, athletes reporting "better" wellness, driven by "better" muscle soreness presented with the highest injury risk when high EWMA ACWR were observed. This suggests that practitioners are responsive to, and/or athletes are able to self-modulate workload activities.

Key words: Sleep, Soreness, Fatigue, Internal load, External load, GPS Playerload

INTRODUCTION

American football is a physically demanding contact sport comprising substantial impact loads and intermittent bouts of high intensity activity (45, 46). Injury rates are correspondingly high and likely associated with the heavy contact loads, however >25% of injuries are attributed to preventable non-contact injury (8). In college football, athletes are typically engaged in 8-9 hours/day of football related activities in addition to 3-4 hours/day in academic classes and home study. The varied injury risks observed across positional groups and with playing experience (relative to educational enrollment status) may yet be a consequence of diverse training and game demands (30). Monitoring, modifying and optimising workloads in college football in an attempt to reduce the number of these injuries is thus an essential player welfare practice (10).

Workload monitoring is indeed commonplace, with global positioning systems (GPS) and built in inertial measurement units (IMU) typically used in college football to quantify training and match workloads (37, 45-47). Across a range of contact team sports, including American college football, increased injury risks have consistently been observed when "spikes" in current (acute) relative to accumulated (chronic) GPS/IMU derived acute:chronic workload ratios (ACWR) are observed (7, 19, 37). The consistency of increased injury risk seen across the literature when high ACWR occur suggests the ratio has merit for workload monitoring practice. However, where absolute (%) risks are reported, ≤25% of athletes exposed to high and very-high ACWR actually suffer an injury (19), and low predictive capabilities have been observed (9, 29). In this regard, one should consider that many sports encompass a range of external training stressors (e.g. running, throwing, contact, resistance training, static work) that contribute to the total workload and it is important to recognise that increased injury risks do not arise from workload spikes *per se*, but from the stress associated with threats to homeostasis by separate and potentially multiplicative intrinsic and extrinsic disturbances (5). Correspondingly, it has been shown that athletes possessing greater fitness are less likely to sustain injury when exposed to ACWR spikes and recover more rapidly from competition induced workloads (20, 25, 27). Indeed, in American College football, whilst workload 'spikes' are informative, some athletes are shown to be more robust and less susceptible to injury when workload spikes are observed (37).

A number of current studies have examined the multiplicative effects of combing external workload measures with consistently greater risks observed with low chronic workloads and a concurrently high ACWR (7, 37). Notably, Colby and colleagues report substantially increased injury risks with heavy non-sport activity and old lower limb pain (7). Pain is commonly reported amongst athletes and may reflect microtrauma associated with overuse injury (6). Considering the high prevalence of overuse injury (15), and reports of athletes frequently participating despite the presence of pain (36, 42), methods for monitoring player wellness are well justified. Indeed, subjective internal stress reports including soreness, sleep, stress and fatigue have been shown to reflect negative responses to high training loads and the frequency of high intensity activity and collisions in sport (33, 40, 43). However, we are unaware of any research that has assessed the effect of external workload "spikes" depicted by ACWR on an athletes subsequent internal self-reported wellness.

Considering quantitative data depicting the athletes internal stress response from wellness reports alongside fluctuating workloads in sport may also provide further insight into an athlete's risk of injury. The current investigation will therefore assess the effect of fluctuating ACWR's on self-reported wellness and examine ACWR-wellness interactions relative to the risk of injury in NCAA American college football.

METHODS

Experimental approach to the problem

Athletic workload and self-reported (subjective) wellness questionnaires collated over a full season (17 weeks) of NCAA Division 1 college football were retrospectively analysed. Previously a 7:21 day coupled ACWR calculated using an exponentially weighted moving average (EWMA) method with a 3-day injury lag period has shown the greatest associations with injury (37). Herein, 7:21 day EWMA ACWR were synchronised with wellness data reported the morning after 3 × weekly main field-training sessions. Any daily file missing self-reported wellness data was removed leaving 1807 aligned wellness/ACWR in-season data files (training days) in the analysis.

Subjects

Forty-two athletes competing for the same Division I-A American college football team (age: 20.5±1.2 yr, mass: 102.8±17.4 kg, height: 186.4±6.7 cm) comprising 7 defensive backs, 8 defensive linemen, 6 linebackers, 8 offensive linemen, 2 quarterbacks, 5 running backs, 5 wide-receivers and 1 tight-end were included in this study. Within this group 7 were Freshman, 7 Juniors, 12 Sophmores and 16 were Seniors. All participants signed an informed consent form upon enrollment indicating that de-identified data collected as part of their athletic participation may be used for research purposes. Participants were specifically informed of the requirements of this study prior to data collection and all experimental procedures were approved by University human ethics committee's and Research Compliance Services.

Procedures

Injuries

Injuries were recorded and documented by the teams athletic training group and classified by incident; date; location; type; and mechanism. As per previous research, diagnoses made by athletic training staff were reviewed retrospectively and confirmed or amended by a sports physician (30). All non-contact injuries reported to medical staff in this investigation resulted in some form of withdrawal from practice or game-time and all were included in the analysis (regardless of ensuing time-lost or not on subsequent days) as this type of injury is considered largely preventable (12).

Quantifying load

Workloads were collected from global positioning systems (GPS) sampling at 10 Hz (Optimeye S5; Catapult Innovations, Melbourne, Australia) during the 3-week pre-season conditioning phase, all in-season 'on-field' workloads (comprising 3 x weekly conditioning sessions, 2 x weekly walk-through sessions) and game day. Data collected by this device is considered a valid and reliable reflection of the activities performed in team sports (21, 41). Only players with workload data from every type of session (pre-season conditioning, in-season conditioning and walk-through days) were included in the analysis. This decision was made in order to include a value for any 'missing' data files (typically due to a malfunctioning GPS unit) in the data. Herein, 37 "missing" pre-season (generalised conditioning) files were included relative to the players individual weekly pre-season average. During the in-season, the individuals average specific to the missing session (GPS devices were typically only worn during one of the two weekly walk-through sessions and for 60 missing conditioning sessions), were added to the data set. Participants wore the same GPS unit in each session. Playerload^{TM}, a variable collected by tri-axial accelerometers within the device sampling at 100Hz and calculated within the manufacturer's software as; the square root of the sum of the squared instantaneous rate of change in acceleration within the three planes divided by 100 (OpenField 1.11, Catapult Innovations, Melbourne, Australia) were used to quantify workloads. Daily exponentially weighted moving average (EWMA) ACWR's were retrospectively calculated by dividing the 7-day (acute), by the 21-day (chronic) workload (37).

Subjective wellness

Each days EWMA ACWR was aligned with wellness reported in a customized wellness questionnaire ~ 2 h before each field training session (11). No data was collected on, or the day after game day (rest day/day off). The questionnaire comprised three 5-point Likert scale questions on self-reported soreness (1 = terribly sore, to 5 = no soreness at all), sleep (1 = slept terrible, to 5 = excellent sleep) and energy (1 = no energy, to 5 = totally energized) and participants were familiarised with all scales. Overall wellness was calculated as the average of the summed soreness, sleep and energy scores for each athlete (1= poor wellness, to 5 = excellent wellness).

Data analysis

Z-score deviations relative to an individual's own mean or "*normal*" score were calculated and expressed as "*better*" (≥ 1 higher than the mean) or "*worse*" (≤ 1 lower than the mean) to determine a meaningful change in wellness, sleep, soreness and energy. The daily ACWR were aligned with the associated self-reported wellness scores (e.g. calculated ACWR following Monday's session were aligned with self-reported wellness z-score scores recorded on Tuesday morning) providing three ACWR/wellness data points per week.

Statistical Analysis

All estimations were made using the *lme4* package (4) with *R* (version 3.3.1, R Foundation for Statistical Computing, Vienna, Austria). The subjective wellness reports were assessed for normality and appropriate parametric or non-parametric correlations performed. A generalized linear mixed-effects model (GLMM) with the complementary log-log link function was used to model the association between ACWR, wellness measures, and injury risk in the subsequent three-day period. ACWR and wellness measures were modelled as fixed effect predictor variables, and player identity was the random effect. A multiplicative term was included in the model to assess the interaction between ACWR and wellness measures. The odds ratios obtained from the GLMM model were converted to relative risks (RR) in order to interpret their magnitude (18). The smallest important increase in injury risk was a relative risk of 1.11, and the smallest important decrease in risk was 0.90 (17). An effect was deemed '*unclear*' if the chance that the true value was beneficial was >25%, with odds of benefit relative to odds of harm (odds ratio) of <66. Otherwise, the effect was deemed clear, and was qualified with a probabilistic term using the following scale: <0.5%, *most unlikely*; 0.5-5%, *very unlikely*; 5-25%, *unlikely*; 25-75%, *possible*; 75-95%, *likely*; 95-99.5%, *very likely*; >99.5%, *most likely* (16). The data is presented as means and 90% confidence intervals (CI) with injury likelihoods estimated at typically very low (-2SD), low (-1SD), mean, high (+1SD), and very high (+2SD) values of ACWR. These values were equivalent to ACWRs of 0.44, 0.67, 0.91, 1.14, and 1.38, respectively.

RESULTS

A total of 55 non-contact injuries were observed in this data set with 27 occurring in game time, 2 during strength-based conditioning, and 26 during field-based practice sessions. 42 injuries were reported in the lower body affecting the ankle (15), knee (11), foot (5), posterior thigh (5), hip (5) and toe (1). The remaining 13 injuries were observed at the lumbar spine and lower back (7), shoulder (5) and elbow (1). A sprain or strain of the affected area encompassed 67% of all injuries and the outstanding 33% comprised three or less diagnosed cases of bursitis, herniated disc, generalized pain, tendinitis, subluxation, plantar fasciitis, patellofemoral disorder, muscular imbalance, impingement, cyst, hyperextension or dysfunction.

Injury risk and daily acute:chronic workloads

The mean ACWR observed in this study was 0.91 ±0.23. A characteristic rise in the probability for injury was observed with high and low ACWR (figure 1). Specifically, injury risks were *very likely* higher when the ACWR was 2SD's above the mean (RR: 3.05, 90% CI: 1.14-8.16) and 2SD's below the mean (RR: 2.49, 90% CI: 1.11-5.58), when compared to the mean ACWR.

INSERT FIGURE 1 ABOUT HERE

Injury risk and wellness

Across the data set, typical mean wellness 3.23 ±0.65, sleep 3.32 ±0.83, energy 3.34±0.78, and soreness 3.05 ± 0.88 was reported. No clear effect on the likelihood of injury with "*better*" (>+1SD) or "*worse*" (<-1SD) reports of wellness, sleep, energy or soreness were observed (Figure 2).

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Effect of ACWR on wellness

Normality across the data set was not observed for any wellness variable and Spearman's correlations between the previous days EWMA ACWR with Sleep, Energy, Soreness and Overall wellness were performed. Significant ($p<0.05$), although *trivial* associations were observed when examining the change (Z score) in subjective ratings with "*worse*" scores in overall wellness (r = -0.06 CI -0.10 to -0.02), muscle soreness (r = -0.07, CI -0.11 to -0.03), and energy (r = -0.05 CI -0.09 to -0.01) observed when a higher ACWR was recorded the previous day.

Wellness, acute:chronic workloads interactions and injury risk

ACWR and wellness interactions highlight that individuals subjectively reporting "*better*" wellness when exposed to a high (+2SD) ACWR had a *likely* higher risk of injury in the subsequent 3 days compared to those reporting *"normal"* (RR: 1.52, 90% CI: 0.91 to 2.54) or *"worse"* levels of wellness (RR: 2.36, 90% CI: 0.83 to 6.74) (figure 3). No clear interactions were observed when examining subjective sleep (p = 0.74) or energy (p = 0.88) and ACWR associations with injury. However, a *likely* and *very likely* increase in the probability of injury was observed when high ACWR (+2SD) and "*better"* muscle soreness were collectively observed in comparison to "*normal"* (RR: 1.64, 90% CI: 1.10-2.47) and *"worse"* soreness levels (RR: 2.78, 90% CI: 1.21-6.38) (Figure 3).

INSERT FIGURE 3 ABOUT HERE

DISCUSSION

In this investigation of collegiate American Football, low and high ACWR's increased the risk of injury. Our results highlight subsequently lower wellness, energy and increased muscle soreness following days that evoked high EWMA ACWR's. Interestingly however the greatest risk of sustaining an injury (within 3 days) was observed when high ACWR and typically "*better*" perceived wellness, driven by perceived levels of soreness were collectively observed. To our knowledge, this study is the first to assess the relationship between an athlete's ACWR and their state of wellness the following day, and the first to consider interactions between the ACWR and perceived wellness relative to the risk of injury.

Playerload^{TM} was the chosen workload measure given it's suitability for encompassing both indoor and outdoor training comprising acceleration, deceleration, sprint, and contact efforts (3, 34) and the frequency of these activities in college football (45, 46). Increased injury risks were observed at lower ACWR's than those commonly reported, however the characteristic 'U' curve depicting a 'sweet spot' at moderate ACWR and injury risks 2.5 to 3 times greater with lower and higher ratios (13) was apparent. In practical terms, the change in workload associated with higher rates of injury at each end of the spectrum represented a relative increase or decrease in load of >40-50% which is consistent with ACWR-injury risks observed across a larger cohort of this group (37). High risk scenarios that may result in the high ACWR and lead to injury in college football such as "return to play" and unaccustomed game time have been proposed (37). However, despite the very likely higher injury risks associated with fluctuations of +/- 2SD from the mean workload in this cohort, the absolute risk did not exceed 15%. Considering the negative effect of high workloads on an athletes self-reported wellness

(33, 40, 43), it was anticipated that lower subjective ratings of wellness observed concurrently with high and/or low EWMA ACWR's would amplify injury risks.

No clear associations between any subjective measure of wellness and the likelihood of injury were observed. However, wellness scores indicative of *"worse"* perceived wellness driven by energy and soreness were observed the day after a high ACWR. These associations appear to extend current research by highlighting the impact of workload spikes (generally) on an athlete's internal wellness. Given the deleterious effects that excessive workloads are known to have on an athlete's sleep (22), it was somewhat surprising that no associations with injury and EWMA ACWR workload spikes were observed. However, increased sleep efficiency has previously been observed during intense training in Rugby League players (39), suggesting that the impact of training on sleep may be positive in the absence of an overtrained or functionally overreached status. Nevertheless, given the apparent negative influence of a high ACWR on subjective rating of wellness and it was anticipated that the risk of injury would correspondingly be amplified with low wellness when considered as multiplicative variables.

It was therefore surprising to observe increased risks were predominantly associated with a high EWMA ACWR when athletes subjectively reported feeling "*better*" driven by perceived levels of soreness. As such, it should firstly be considered that the negative associations between EWMA ACWR and wellness we observed were *trivial* and the impact should be interpreted with caution. Furthermore, the association between soreness and high EWMA ACWR's observed in this investigation were likely affected by typically higher workloads on (35), and consistently increased muscle soreness following (11) game-day. The impact of games on subjective wellness has also been shown to perpetuate and deteriorate throughout the training week up to 4 days post game (11). Subjective reports of *"worse"* perceptions of wellness prior to training can reduce training outputs (14, 26) and more specifically *"worse"* muscle soreness has previously been related to a reduction in player effort (s-RPE) in college football players (15). It is possible that practitioners are responsive to negative wellness perceptions and may have intervened in this investigation to modulate training loads and/or players themselves may have self-regulated reductions in their training effort. Such actions may explain the low sensitivity that ACWR models have shown with injury (9, 29). Consistent with this theory, an athlete reporting *"better"* wellness and soreness may alternatively be pre-disposed to more frequent high intensity activities that are considering injury initiating events such as sprinting, accelerating and cutting (2, 24). Although we acknowledge that this remains speculative, further research focusing on the relationship of daily fluctuations in subjective recovery responses and training outputs is warranted.

Limitations

The results of the current research do not suggest that adverse wellness increases the risk of injury. The pattern of injury was comparable to those reported in a recent longitudinal study (23) and previous accounts of the daily and seasonal GPS workload distribution in this team (32) are similar to that observed in other groups of NCAA division I footballers (44). However, a number of limitations must be recognised. Firstly, one should recognise that despite the similarities noted above, the current study is a report of a single season of injuries from a single team. As such, these outcomes may not be consistently reflected across college football when considering the varied training demands/schedules employed. Furthermore, whilst the number of injuries included in this investigation were considered sufficient to detect moderate-strong associations (1), the overall number was relatively low, and the associations observed were likely underpowered by examining interaction effects. Furthermore, in this and many similar investigations examining injury risks and workloads in team sports, only field-based workloads are considered. As such, although wellness may have been impacted on by workloads (such as resistance exercise) that were not measured in this investigation they were not included in the ACWR calculation. In addition, the variability in workload and injury risk that may be associated with positional demands and experience may have influenced our results (30) and academic, or other non-athletic stressors which can adversely affect wellness and amplify injury risks (28), were not recorded and could not be considered. Inadvertently more complex and confounding variables that influence fatigue, wellness, external and internal stress may thus have contributed to the risk of injury observed (31). The higher injury risk observed with high workloads and "*better*" wellness observed in this study may suggest that these confounding variables did not influence our results. However, the accuracy of the wellness reports used in this investigation should also be considered. Variations in wellness relative to game day have previously been observed from the 5 point Likert scale used in this investigation (11), the assessment thus appears sensitive to workloads inducing fatigue. At present the REST-Q is however the only wellness questionnaire that appears to have empirical evidence to show reliability relative to acute and chronic load variations (38).

CONCLUSION

In this investigation, athletic workload spikes resulted in reduced perceptions of wellness the following day, however the relationship was trivial. In contrast, the most at-risk group were athletes reporting *"better"* wellness driven by energy and muscle soreness. We suggest that this unexpected association may be a consequence of responsive practitioners applying interventions when negative perceptions of wellness are observed and, or effective self-modulation from players themselves. In this regard, it is also possible that high intensity activities which evoke an inherently greater risk of injury occur more frequently when athletes report "better" wellness. Future studies examining acute injury risks relative to wellness and high intensity activities are thus warranted.

PRACTICAL APPLICATIONS

Collectively, this study supports the use of simple non-invasive wellness measures to complement, injury monitoring and external load constructs within an effective athlete monitoring system for American Football. Specifically, we suggest practitioners 1) apply wellness monitoring within their daily practice to understand the affect and effect of training workloads; 2) where possible, utilise an EWMA ACWR and avoid daily fluctuations >1SD of a player's average and; 3) closely monitor the workload and its composition relative to the planned activity, avoiding unplanned increases in workload even if "better" wellness is apparent.

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Figure descriptions:

Figure 1: Predicted probability of injury in college football players with deviations from the mean EWMA ACWR.

Figure 2: Predicted probability of injury in college football players with deviations from the mean subjectively reported sleep, soreness, energy and overall wellness

Figure 3: Interactive effect of a deviation from the mean EWMA ACWR when collectively considering a athletes state of perceived a) Overall Wellness, b) Soreness, c) Energy and d) Sleep Quality